XR-3 CENTER OF GRAVITY CHARACTERISTICS.

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

XR-3 CENTER OF GRAVITY CHARACTERISTICS

by

William M. Leins

March, 1975

Thesis Advisor: Donald M. Layton

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Testing of the XR-3 Captured Air Bubble Testcraft was accomplished to determine the center of gravity location which results in the minimum thrust required for a given velocity. The optimum center of gravity was determined to be one hundred and nineteen inches forward of the stern transom for velocities higher than twelve knots.

XR-3 Center of Gravity Characteristics

by

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ABSTRACT

Testing of the XR-3 Captured Air Bubble Testcraft was accomplished to determine the center of gravity location which results in the minimum thrust required for a given velocity. The optimum center of gravity was determined to be one hundred and nineteen inches forward of the stern transom for velocities higher than twelve knots.

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I. INTRODUCTION

A. THEORY

In recent years the concept of air cushion vehicles (ACV) has been developed into several operational systems. ACVs have been developed for overland operation, sea operation, or a combination of both. Such vehicles designed to operate solely on or over water are usually termed Surface Effects Ships (SES). Surface Effects Ships are usually classified as either the Captured Air Bubble (CAB) type or the Hovercraft (GEM - Ground Effects Machine) type.

The Captured Air Bubble vehicle employs air-constraining "skirts" which extend from the vehicle to below the surface of the water on the bow and stern, and has solid sidewalls. The walls and skirts all contact the water, forming a hollow chamber (plenum) beneath the boat into which pressurized air is ducted. The pressurized air acting on the plenum area provides most of the lift of the testcraft so that the immersion depth of the CAB is minimal (six to ten inches for the XR-3). Previous testing has shown that to operate efficiently the CAB craft must accelerate to a speed high enough to overcome the large drag forces that are present at low velocities. This is referred to as getting "over the hump." Once over the hump, the CAB operates "on the cushion." In other words, once the craft accelerates over the hump, it rides efficiently on a cushion of captured pressurized air.

Hovercraft, while labeled an SES, operates on a different principle altogether. Hovercraft utilize lifting fans to keep the craft just above the surface of the water; thus, they can operate efficiently in ground effect. However, the important thing to note is that the entire craft must be lifted out of the water.

It is generally acknowledged that one of these two types of SESs must be employed to overcome the fifty miles per hour maximum practical speed restriction for displacement ships (Ref. 1). The Hovercraft has the advantage of no hydrodynamic drag, but its limiting factor is that the weight of the engine necessary to produce enough lift for larger size ships soon takes too much of the total weight of the craft to be practical. The CAB has the advantage that it requires a relatively small amount of power to maintain the vehicle on the bubble.

B. THE XR-3

The XR-3 Testcraft was constructed by the David Taylor Model Basin (now designated Naval Ships Research and Development Center [NSRDC]) in 1966. Figures 1 and 2 show the general configuration of the testcraft. The craft is twenty-four feet long, twelve feet wide and presently weighs about 5,800 pounds. It is propelled by two forty hp. outboard motors, and the plenum pressure is maintained by one or more of five blowers, each powered by a small internal combustion, four-cycle, air cooled engine.

The Navy-conducted test program was terminated on 26 October 1967 in accordance with instructions from Joint Surface

Effects Ships Project Office (JSESPO), and the XR-3 was shipped to Aerojet-General Corporation for further testing and evaluation on 6 December 1967. Aerojet-General Corporation operated the XR-3 Testcraft in San Diego Bay for some one hundred and eight hours of water-borne operations between April and November 1968.

In March 1970 the XR-3 was transferred to the Naval Postgraduate School (NPS) in Monterey, Ca. for the purpose of investigating several areas of interest in the field of basic and advanced surface effects ships technology in accordance with a JSESPO statement of work.

The XR-3 is still in operation at the time of this report and has been the source for numerous theses by NPS students in a wide range of areas.

C. REQUIREMENT

Although a considerable amount of testing has been accomplished on the XR-3 Testcraft both at the Naval Postgraduate School and elsewhere, the effects of C. G. variation have been felt to be negligible in most cases. This is primarily due to the fact that the construction of the XR-3 is such that in order to vary the C. G., ballast must be brought aboard and placed at various locations on the deck. Since this was not done in previous tests the actual C. G. variation was indeed quite small and of no consequence to the outcome of the test.

However, as testing has progressed on the XR-3 through the years, large amounts of data have been collected on the

inherent characteristics of a captured air bubble craft. These data are being used by the simulation groups in developing and validating mathematical models for simulation of larger captured air bubble craft. Also, future test plans for the XR-3 call for very specific C. G. locations, plenum pressures, and seal positions.

This report is the first study on the effect that the C.G. has on different performance characteristics of the XR-3. It is an attempt to locate the optimum C. G. to be used for future testing and to validate the assumption of negligible effects of C. G. movement in previous tests.

II. TESTING PROCEDURES

A. INSTRUMENTATION

During the period of time (June, 1972 to February, 1973) that the XR-3 was being fitted with a new type of membrane seal the onboard data acquisition system was expanded and improved in order that extensive performance testing of the modified testcraft could take place (Ref. 3 and 4).

For this test plan it was necessary to measure the thrust between zero to five hundred pounds and the velocity between zero and forty knots.

The data were recorded on a Pemco Model 120-B magnetic tape recorder which is capable of recording $\pm$ 1 volt RMS $\pm$ .5% on each of fourteen data tracks. The parameters under consideration, port/starboard thrust and velocity, were recorded simultaneously on separate tracks. The signal from

each of the port and starboard thrust transducers was amplified so that a recorded range of zero to one thousand mv was equivalent to zero to five hundred pounds thrust. The velocity transducer/amplifier circuitry was set up so that zero to one thousand mv input to the recorder was equivalent to zero to forty knots.

To interpret the data a portable data reduction system was developed for the XR-3 (Ref. 5). This system consists of four major units. The Pemco magnetic tape recorder is used for data playback. The data are fed into a signal conditioner unit with a built-in analog-to-digital converter which is used to filter, amplify, sum and further prepare the data for transmission to either a strip chart recorder or a digital X -Y plotter through a Monroe 1880 calculator.

This entire system is housed in a Champion Mobile Home which enables on-site data reduction. Since the tests are performed approximately one hundred miles from the school, this greatly facilitates interpretation of the day's runs and planning of the next day's runs.

B. INITIAL WEIGHT AND BALANCE

The initial weight and balance determinations for the XR-3 testcraft were performed at the facilities of the Department of Aeronautics, Naval Postgraduate School. The testcraft was hoisted by its four-point suspension system by an overhead crane with a dynamometer installed between the crane hook and the hoisting cables. This dynamometer was calibrated prior to the hoisting on a testing machine, and was rechecked after the hoisting to insure accuracy.

Trim determinations were made in two manners. First the testcraft was allowed to pitch up on the hoisting slings until it reached an equilibrium position. This pitch angle was measured and the location of the center of gravity was obtained by trigometric calculations. The craft was then ballasted so as to provide zero pitch angle, and the location of the center of gravity was calculated both at this loading and at the original hoisting weight. These two methods resulted in center of gravity locations within one-quarter of an inch. All C. G. locations are referenced to the stern transom line inasmuch as this is square edge normal to the centerline of the testcraft.

Variations to the original weight and balance were computed by listing weights added or removed together with their lever arms and moments. The basic craft weight with full fuel, instrumentation, tool box and the project director in the pilot seat was 5,810 pounds with a center of gravity one hundred and nineteen inches forward of the stern transom.

C. CHANGING THE WEIGHT AND BALANCE

When the XR-3 was constructed it had three built-in water tanks, two in the bow and one over the fuel tanks, to be used for ballast. This proved to be impractical because the craft was too bow-heavy and the fuel tanks were located at the initial C. G. Adding water to the tank over the fuel tanks only increased the weight and had no effect on the C. G. Adding water to the bow tanks had an adverse effect on the trimming of the craft.

In its present configuration there is no practical way to vary the trim of the XR-3 without adding ballast. Changing the fuel load only changes the weight since the fuel tanks have a center of gravity one hundred and nineteen inches forward of the stern transom, a position that was confirmed as the optimum.

Three methods were used to vary the C. G. A plastic water tank was placed on a scale and calibrated in fifty pound increments as it was filled with water. Calculations were made to determine the locations for this tank when filled with two hundred and fifty pounds of water for various testcraft centers of gravity. The deck was marked accordingly, and the tank was moved along the centerline of the XR-3 as necessary for each run. After struggling with a two hundred and fifty pound tank of water this system was given up in favor of two one hundred and twenty-five pound tanks of water which were moved along each side. The third method was to use human ballast. Passengers were weighed and stationed at various positions on the deck. This was extremely useful when it was necessary to vary the C. G. during a given run while holding the throttle setting constant. This method was used extensively during the latter stages of the testing program.

D. TESTING METHODS

As previously stated, although the XR-3 is capable of measuring fourteen different parameters, for this report it was necessary to measure only the thrust and velocity of the XR-3 at a given C. G. location.

Each day's test program consisted of a series of runs and, for each run, measurements of thrust and velocity taken between maximum throttle and the lowest speed at which the XR-3 would stay on the "hump" at a given weight and C. G. location.

In the early part of the testing program the C. G. was fixed and the XR-3 was accelerated to full throttle. When the speed of the craft stabilized, the pilot started the tape recorder and gave informative notes as necessary to correlate the data as it was played back in the data reduction phase. After stabilization at a given velocity the throttle was reduced and the craft decelerated to a slower velocity. Each run consisted of varying the velocity all the way down to just befor the "hump" (approximately eight knots), then back up to maximum velocity.

After reviewing some of these early runs on the strip chart recorder it was obvious that this method had several drawbacks. What was frequently thought by the pilot to be a constant velocity was often either still decreasing or increasing and not yet stabilized. This was due to the large amount of time it took the XR-3 to stabilize at a new velocity when the throttle position was moved.

A second method of testing was then developed. The XR-3 was stabilized at a given velocity, throttles were set and not moved; then by using the human ballast method described in Section C, the C. G. was varied as required. The velocity change, due to moving the C. G., was found to be very small and as a result the stabilized velocity was reached much sooner.

The XR-3 was tested at various velocities for the following seven different C. G. locations and weights of 6,020 pounds and 6,270 pounds.

C. G. Position	-	Inches Forward of Stern Transom
1	-	115
2	-	116
3	-	117
4	-	118
5	-	119
6	-	120
7	-	121

The C. G. locations were precomputed and marked on the deck for a given ballast.

III. RESULTS

The test runs were made between April and December, 1974. Due to the voluminous amounts of data recorded the data were averaged for two given basic weights and three C. G. positions (Fig. 5).

The variation of thrust required (drag) vs. velocity for various C. G. locations was plotted as shown in Fig. 5 - 10. Fig 11 shows thrust required vs. C. G. for various velocities. Fig. 12 shows thrust vs. velocity at C. G. equals one hundred and nineteen inches for the two basic weights. Fig. 13 shows thrust vs. velocity for the same weight but at two different C. G. locations.

IV. DISCUSSION OF RESULTS

From Figs. 5 - 10, it can be seen that the basic shape of the thrust-velocity curve remains constant throughout the range of parameters tested. As the testcraft goes over the "hump", there is a marked decrease in the thrust required. As velocity increases, there is an almost flat part to the curve with a very slightly increasing thrust required for increase in velocity up to approximately twenty-two to twenty-three knots; after which, the slope of the curve greatly increses as maximum velocity is reached. This is characteristic of the CAB craft and the major reason why this type of craft is so appealing to the future planners of the Navy.

From Fig. 11, it can be determined that for the velocities from twelve to twenty-four knots, the optimum C. G. positon is one hundred and nineteen inches. However, for speeds slower than twelve knots, it is hard to determine the best C. G. location. For one thing, the testcraft is very close to the "hump" and not fully stabilized on the "bubble". With an aft C. G. location, the testcraft's bow is high, and venting of pressure occurs from the plenum area of the craft. Once this occurs the effective lift is reduced and the thrust required is greater. When the C. G. is forward, the testcraft becomes bow heavy and has a plow-in tendency.

Fig. 12 shows that with an increase in weight, the thrust required is greater at all velocities and the and the maximum

velocity is lower at the increased weight. This is what would be expected in any case and the comparison was used to validate the data.

The last figure in this report, Fig. 13, is a comparison of the thrust vs. velocity at the extreme C. G. positions tested. It should be noted that if a curve at what was found to be optimum C. G. position was added (one hundred and nineteen inches), it would be lower than both curves shown. This figure shows that by moving the C. G. forward from the aft C. G. position the venting from the plenum chamber is reduced; the bow moves down giving the craft a better trim, moving the thrust vector from slightly below horizontal to horizontal. Moving the C. G. further forward, past the optimum position, makes the craft bow heavy and it has a tendency to "dig in" and vent plenum pressure out the aft seal.

In summary, the optimum C. G. positon for the XR-3 at velocities of twelve knots and greater was found to be one hundred and nineteen inches measured from the stern transom. Since this corresponds to the actual C. G. position of the XR-3 without ballast added, the previous assumptions that the XR-3 was operating at the optimum C. G. position have been correct as substantiated by this report.

V. RECOMMENDATIONS

Although the optimum C. G. position has been found for the present configuration of the XR-3, it is recommended that further testing be performed to analyze the various changes in performance that might occur when the seal position is varied, both front and rear, for various seal pressures and C. G. locations. It would be worthwhile to find out if the optimum C. G. position is the same for all configurations of the XR-3 and, if there are changes, what are the causes. In order to answer these questions, it would be necessary to develop a method of measuring the lift and the drag of the seals. Subtracting the seal lift and drag from the gross lift and drag would provide the lift/drag of the hull alone. This would enable one to find the optimum, maximum L/D ratio, seal position for various seal pressures.

FIGURE 1. XR-3, TESTCRAFT - GENERAL APPEARANCE

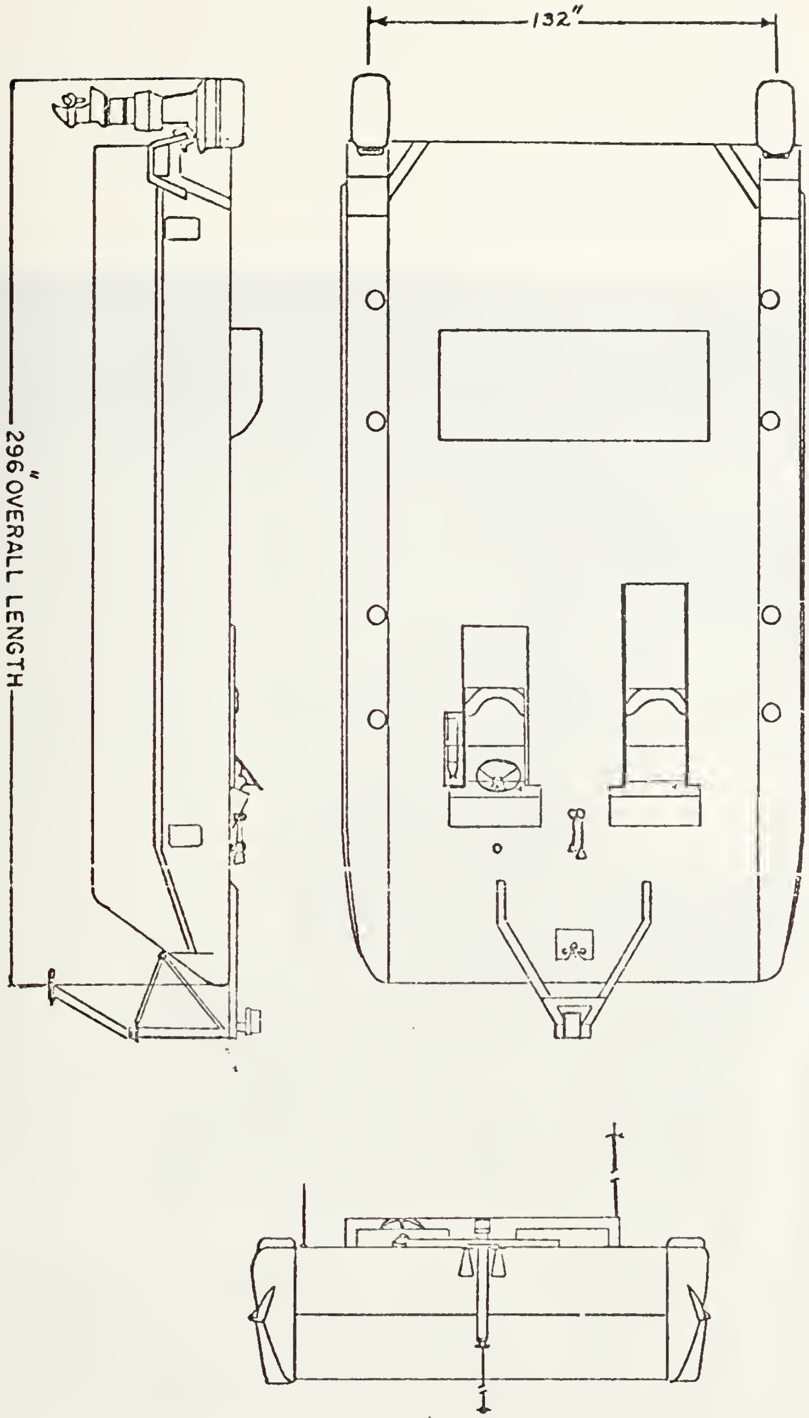

FIGURE 2. GENERAL CONFIGURATION OF XR-3

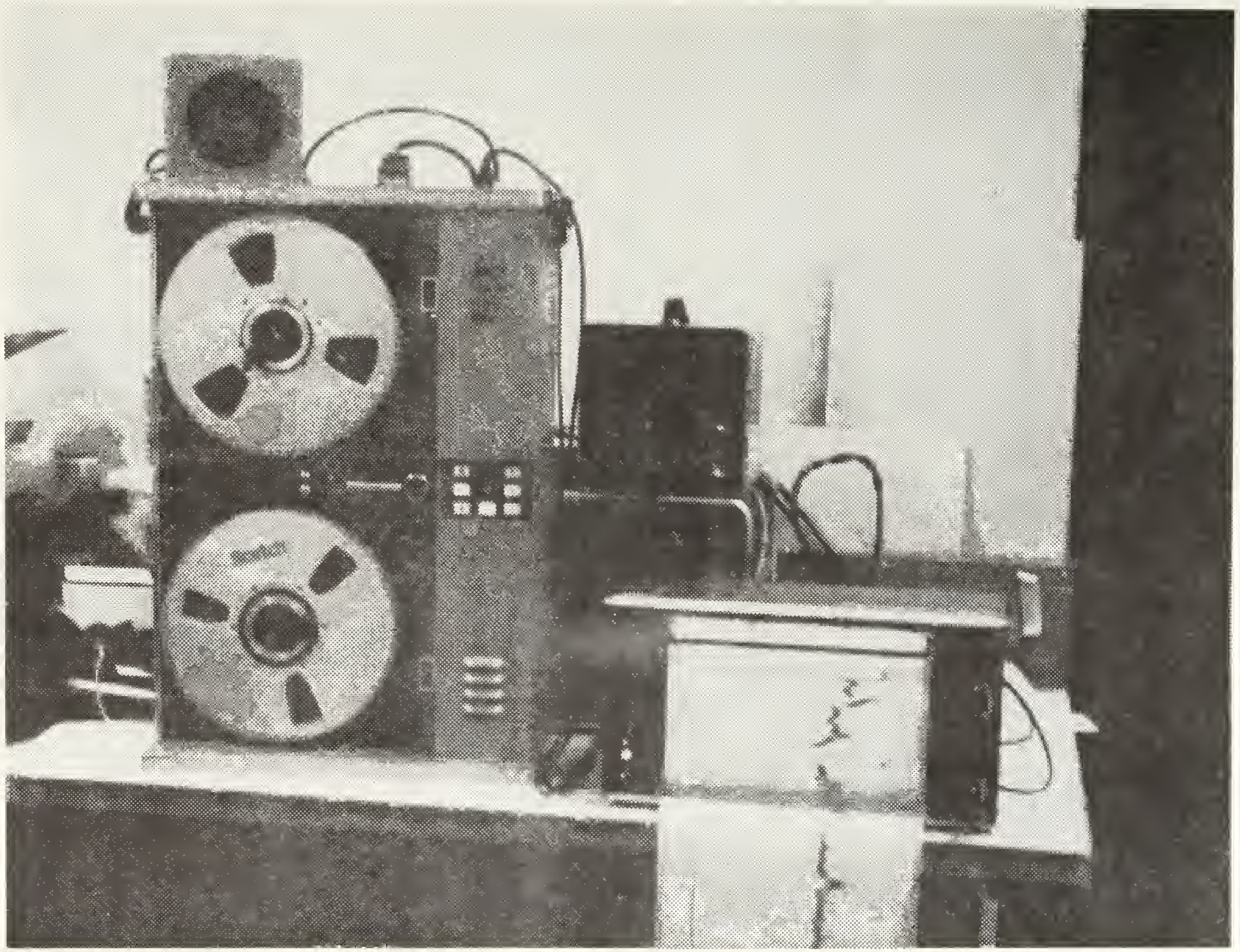

FIGURE 3. DATA REDUCTION SET-UP

TABLE OF DATA FOR THE XR-3

	WT = 6,020 Pounds			WT = 6,270 Pounds		
	C. G. Position			C. G. Position		
	116.8	119.0	121.0	117.5	119.0	121.0
Velocity (Knots	Thrust (Pounds)					
8	457	463	448	439	479	468
9	400	392	385	400	437	410
10	381	370	372	392	399	395
11	372	357	366	392	385	391
12	368	352	362	394	386	390
13	368	352	363	394	386	390
14	367	352	365	395	386	391
15	371	357	369	397	388	392
16	377	358	370	397	388	393
17	382	359	372	398	389	395
18	387	361	376	399	390	397
19	392	362	380	407	400	399
20	399	365	382	415	403	400
21	405	368	385	425	405	410
22	417	380	400	447	417	430
23	430	397	414	475	428	479
24	448	421	437	499	471	490

Figure 4

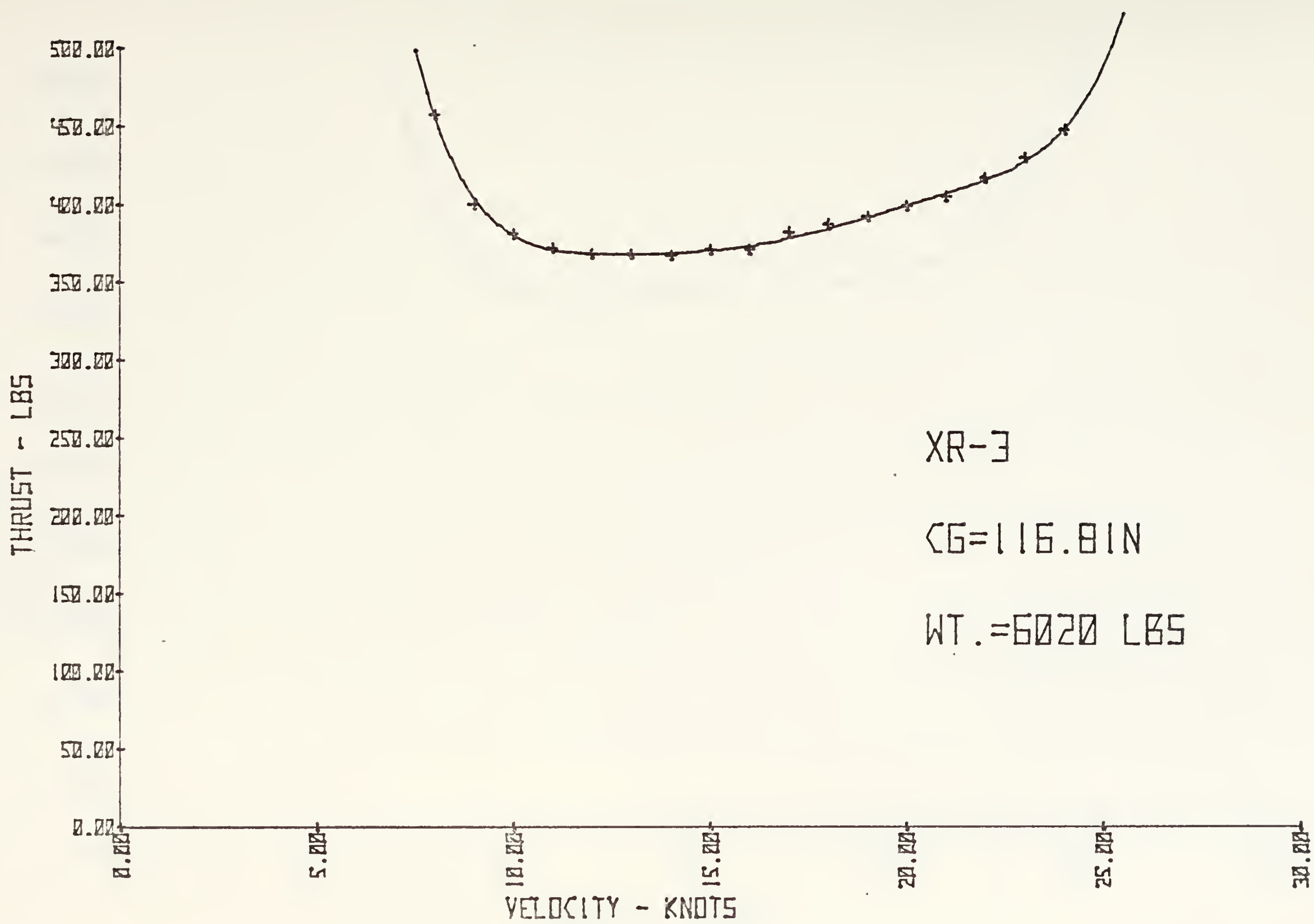

FIGURE 5, PLOT OF THRUST VS. VELOCITY FOR C. G. = 116.8 INCHES, WEIGHT = 6020 POUNDS

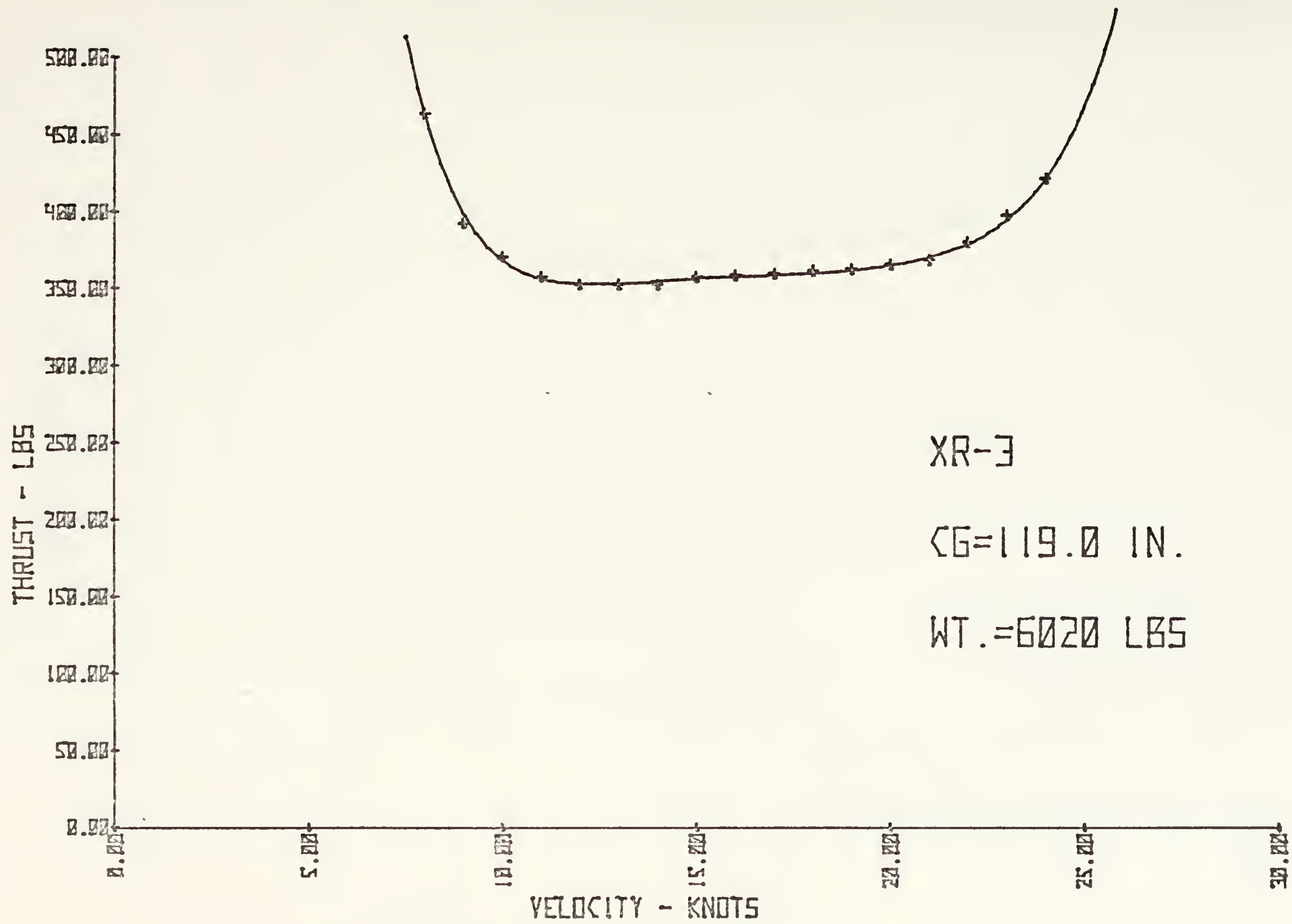

FIGURE 6. PLOT OF THRUST VS. VELOCITY FOR C. G. = 119.0 INCHES, WEIGHT = 6020 POUNDS

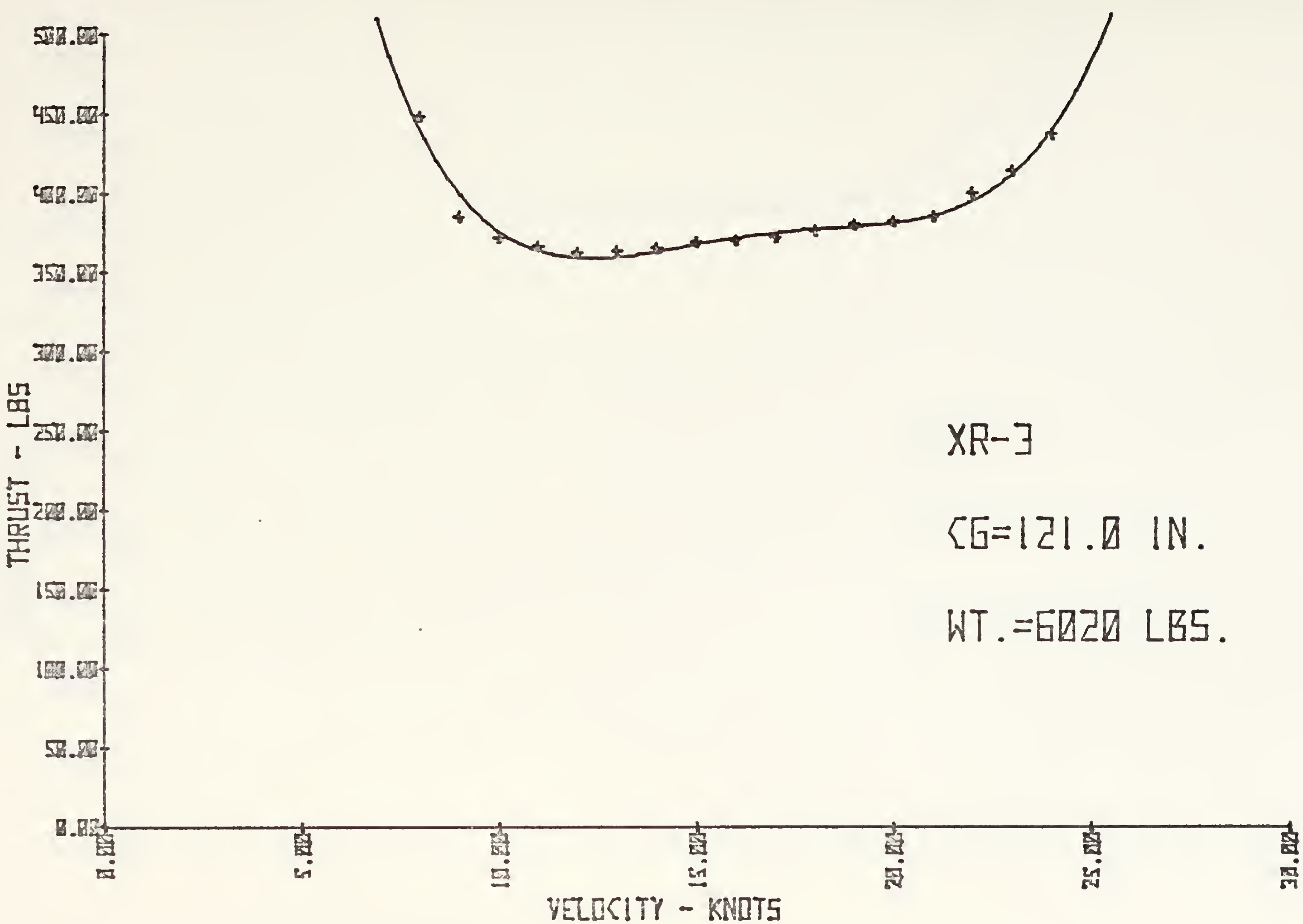

FIGURE 7. PLOT OF THRUST VS. VELOCITY FOR C. G. = 121.0 INCHES, WEIGHT = 6020 POUNDS

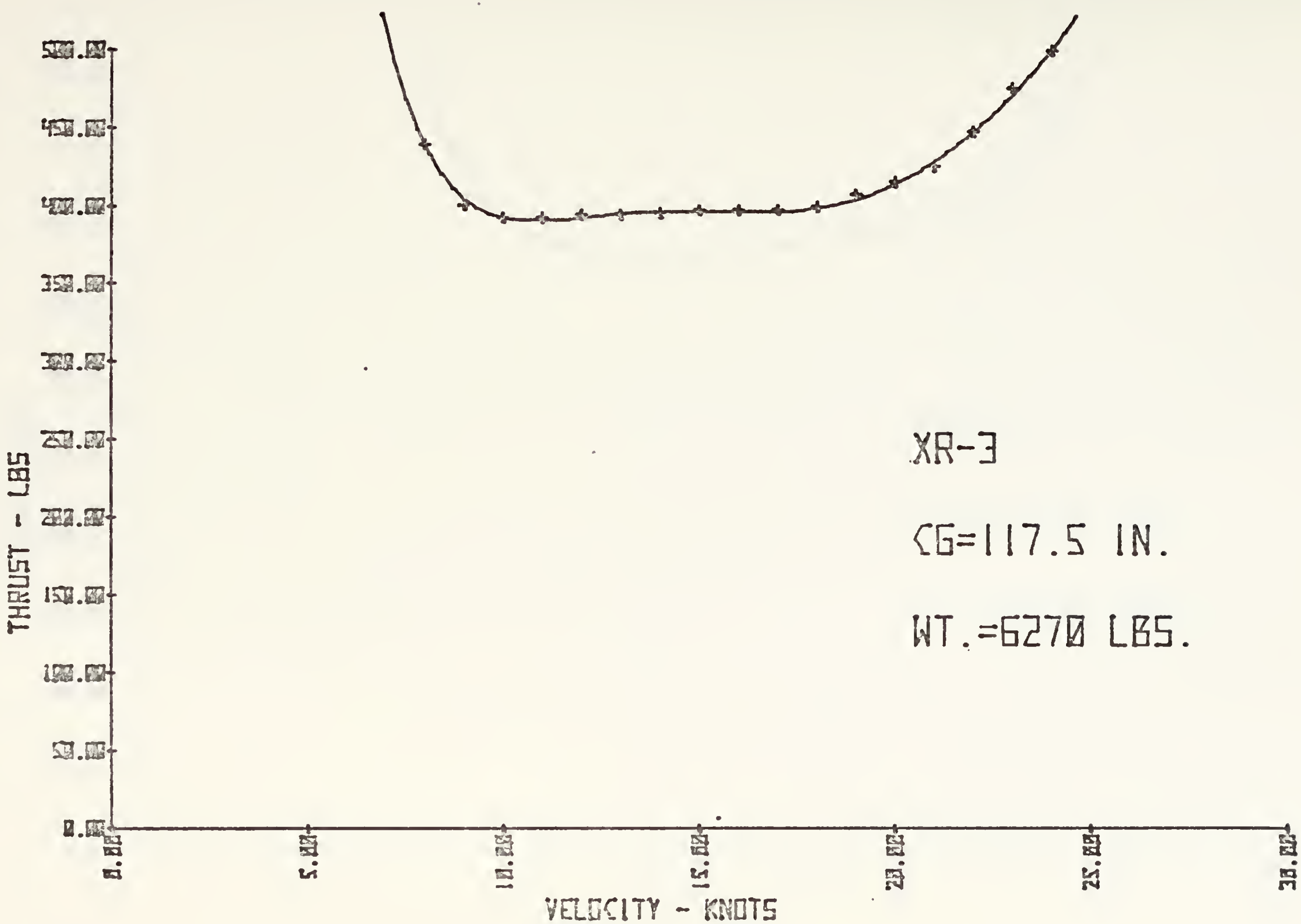

FIGURE 8. PLOT OF THRUST VS. VELOCITY FOR C. G. = 117.5 INCHES, WEIGHT = 6270 POUNDS

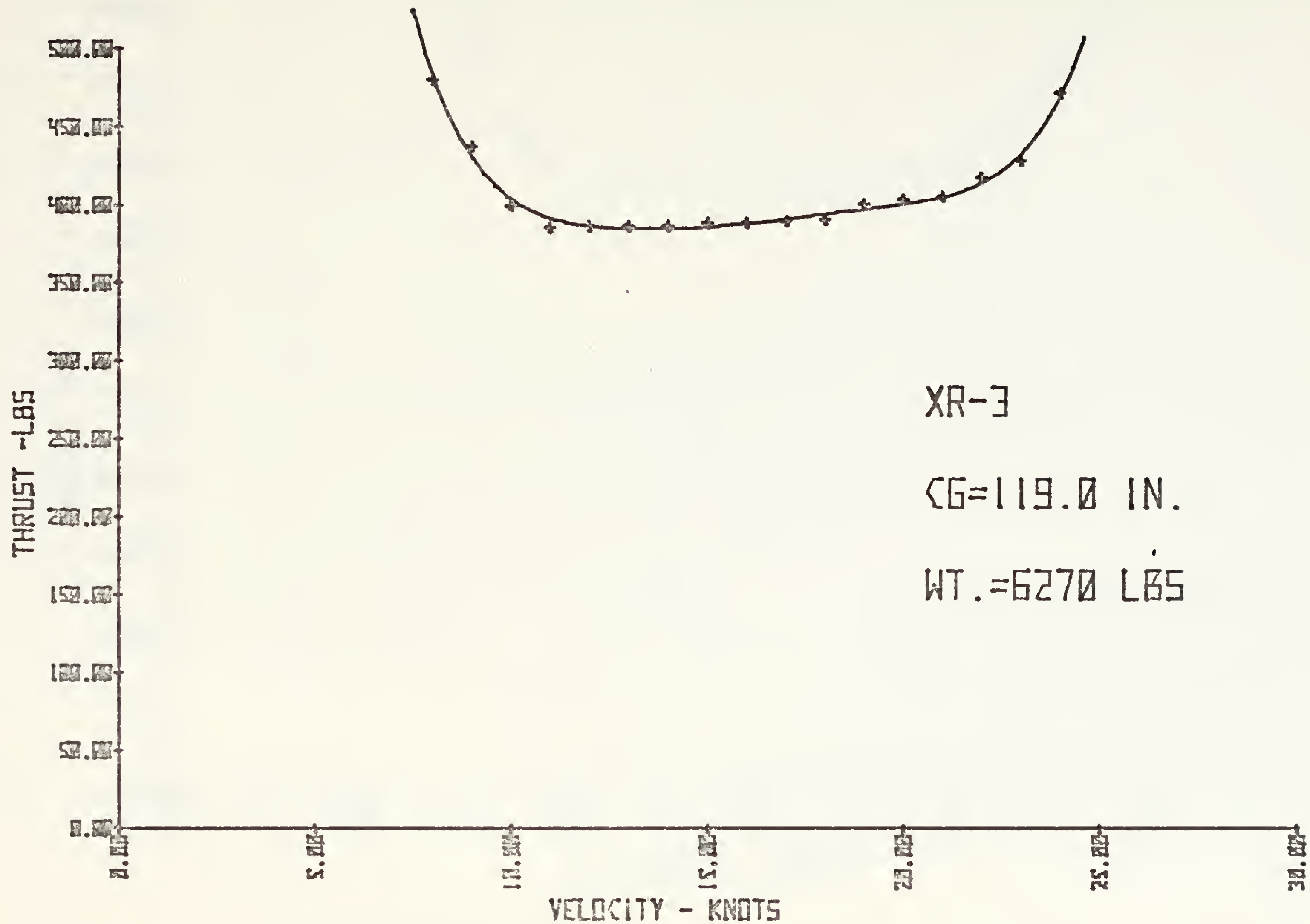

FIGURE 9. PLOT OF THRUST VS. VELOCITY FOR C. G. = 119.0 INCHES, WEIGHT = 6270 POUNDS

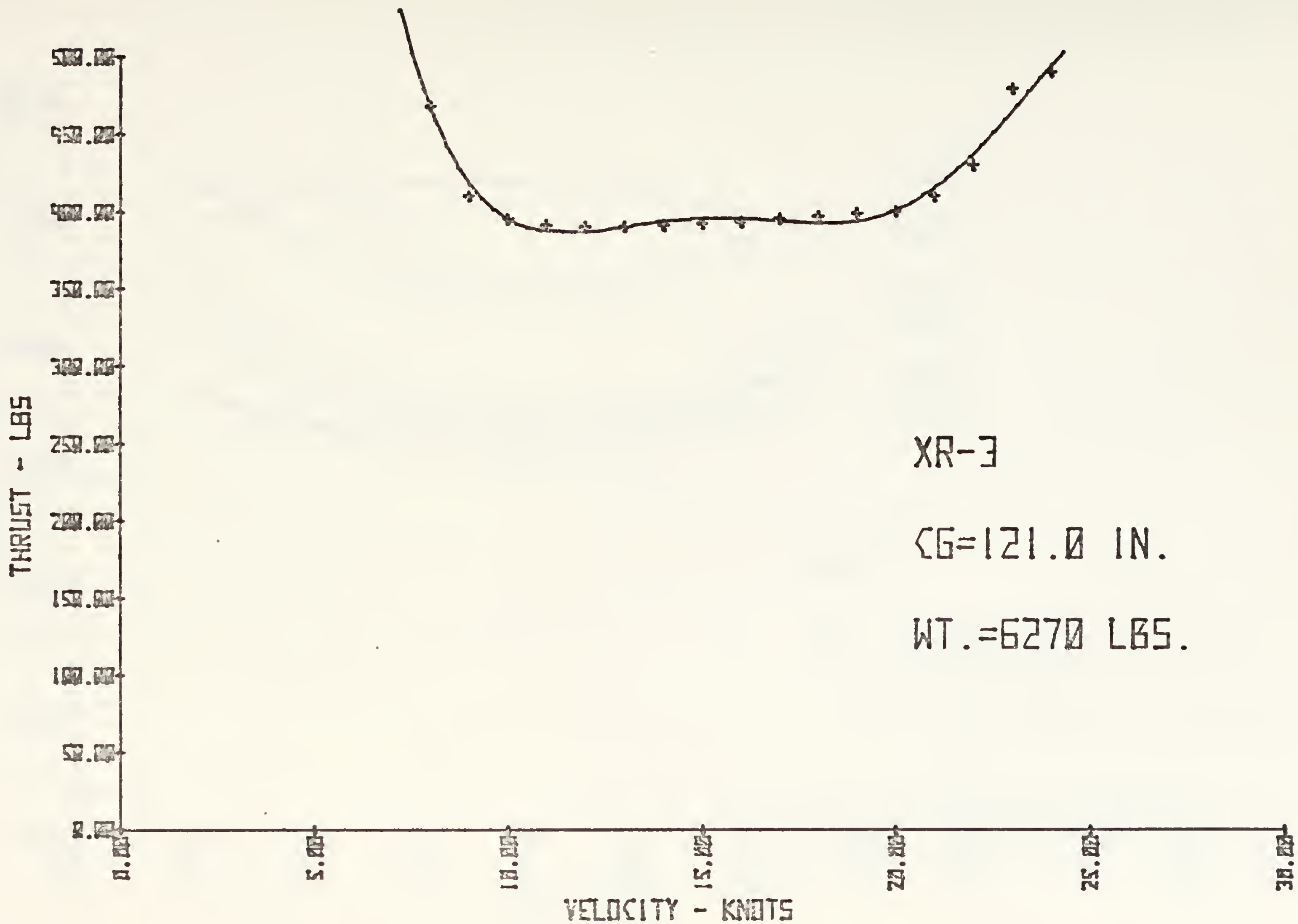

FIGURE 10. PLOT OF THRUST VS. VELOCITY FOR C. G. = 121.0 INCHES, WEIGHT = 6270 POUNDS

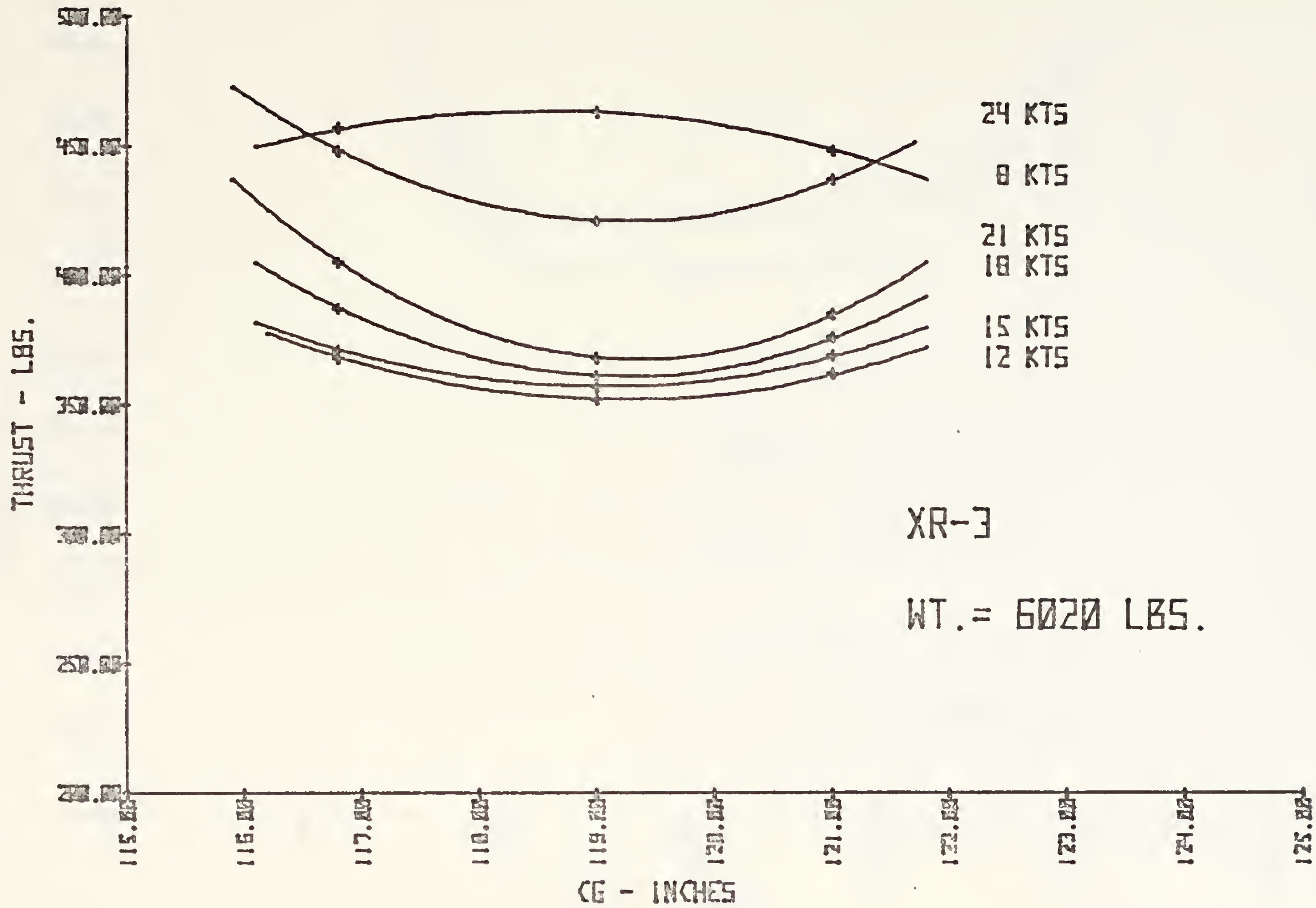

FIGURE 11. PLOT OF THRUST VS. C. G. FOR VARIOUS VELOCITIES

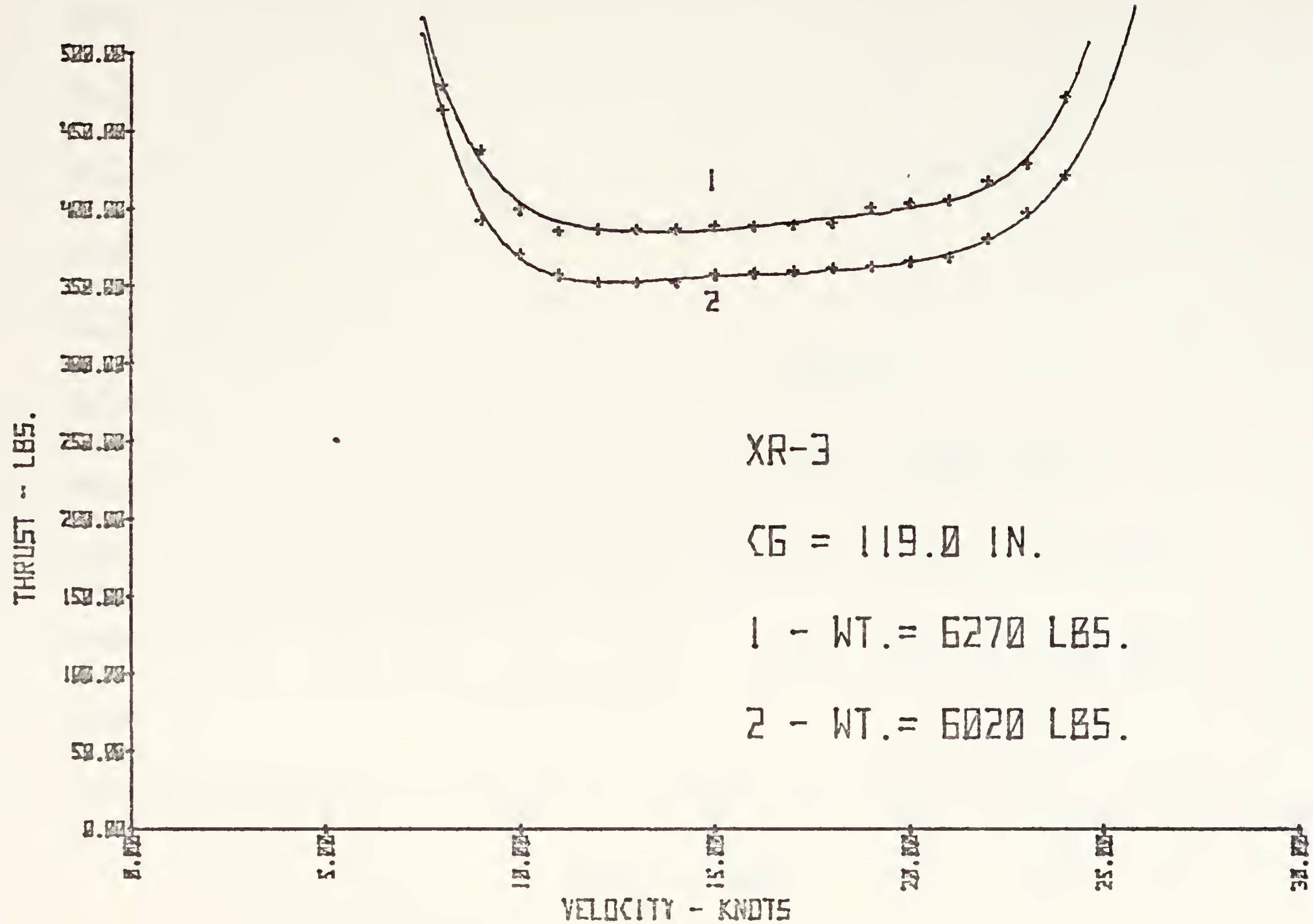

FIGURE 12. PLOT OF THRUST VS. VELOCITY FOR 1 C. G. AND 2 WEIGHTS

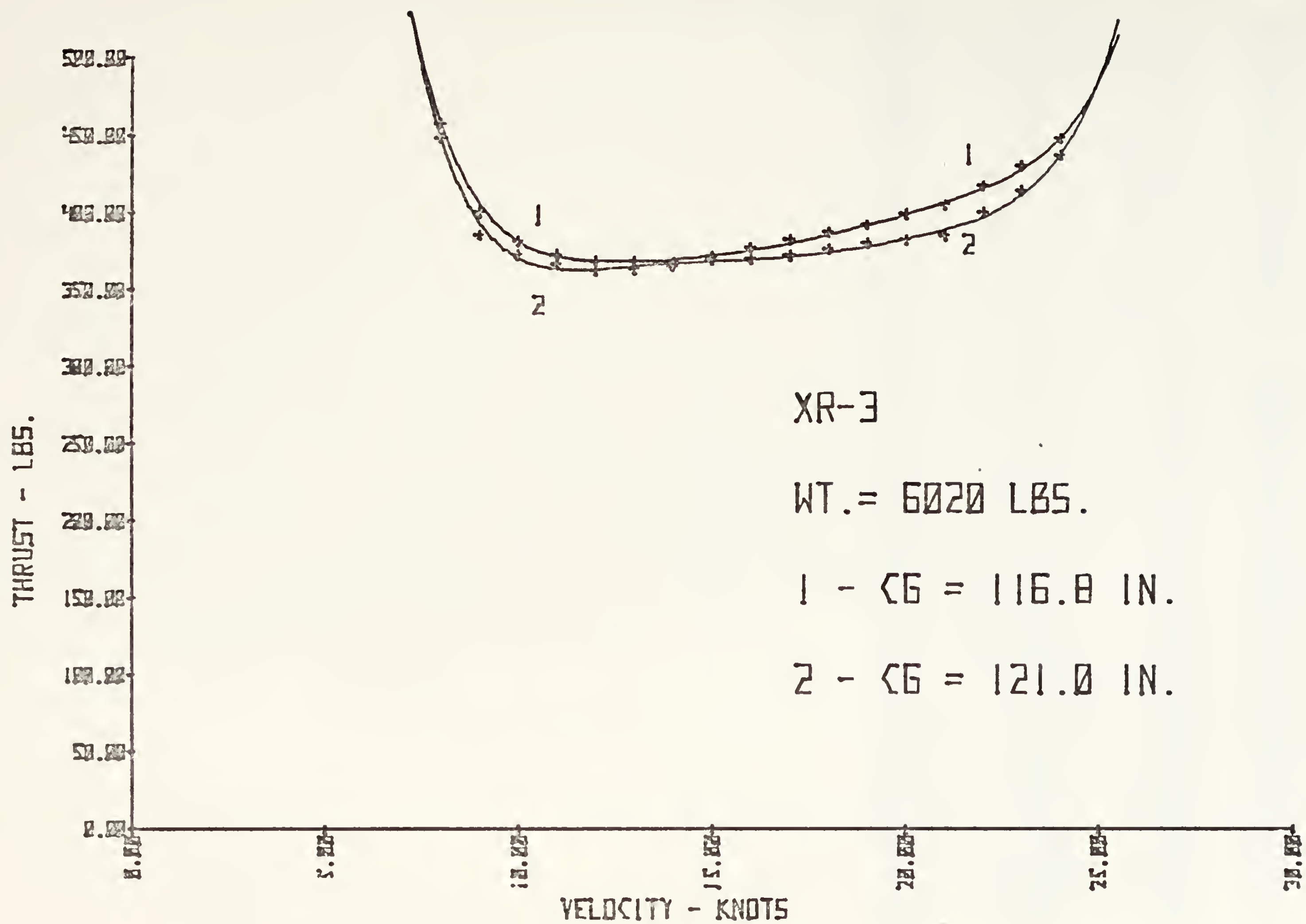

FIGURE 13. PLOT OF THRUST VS. VELOCITY FOR 2 C. G. AND 1 WEIGHT

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